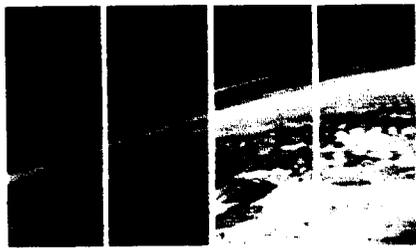


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WORKSHOP ON INNOVATIVE INSTRUMENTATION FOR THE IN SITU STUDY OF ATMOSPHERE-SURFACE INTERACTIONS ON MARS



MSATT

Mars Surface and Atmosphere Through Time

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WORKSHOP ON INNOVATIVE INSTRUMENTATION
FOR THE *IN SITU* STUDY OF
ATMOSPHERE-SURFACE INTERACTIONS ON MARS

Edited by

Bruce Fegley Jr. and Heinrich Wänke

Held at

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October 8–9, 1992

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Program

Thursday, October 8, 1992

Morning Session

09:15 Welcome by H. Wänke

Chair: R. E. Arvidson

09:30 Fegley B. Jr.*
An Overview of Important Scientific Questions about Atmosphere-Surface Interactions on Mars

10:00 Barlow N. G.*
Database of Proposed Payloads and Instruments for SEI Missions

11:00 Martin T. Z.*
Atmospheric Imaging from Mars Landed Stations

11:30 Arvidson R. E.* Shepard M. K. Rivard B.
The Potential Utility of Spectral Reflectance and Emission Observations to Martian Landers

Afternoon Session

Chair: L. M. Mukhin

14:00 Treiman A. H.*
Optical Luminescence Spectroscopy as a Probe of the Surface Mineralogy of Mars

14:30 Lindner B. L.*
Does UV Instrumentation Effectively Measure Ozone Abundance?

15:00 Grant J. A.* Schultz P. H.
Ground Penetrating Radar as a Tool for Investigating Near-Surface Stratigraphy on Mars

* Denotes speaker

- 16:00 Muhleman D. O.* Janssen M. A. Clancy R. T. Frerking M. Gulkis S. McCleese D. J.
Zurek R. Haberle R. M.
Temperature/Pressure and Water Vapor Sounding with Microwave Spectroscopy
- 16:30 Mukhin L. M.* Huth J. Wänke H. Dikov Y. Koscheev A. P.
Preliminary Experimental Results of UV Irradiation of Carbonates
- 17:00 Koscheev A. P.* Mukhin L. M.
Mass Spectrometric Studies of Interaction of Martian Atmosphere Gas Components with Ferric Oxide Surface Under UV-Illumination

Friday, October 9, 1992

Morning Session

Chair: K. Mauersberger

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In Situ Identification of the Martian Surface Material and Its Interaction with the Martian Atmosphere Using DTA/GC
- 09:30 Mauersberger K.* Mahaffy P. Niemann H.
Mass Spectrometer-Pyrolysis Experiment for Atmospheric and Soil Sample Analysis on the Surface of Mars
- 10:00 Gooding J. L. Ming D. W.* Allton J. H. Byers T. B. Dunn R. P. Gibbons F. L.
Pate D. B. Polette T. M.
Determination of Martian Soil Mineralogy and Water Content Using the Thermal Analyzer for Planetary Soils (TAPS)
- 11:00 Wright I. P.* Grady M. M. Pillinger C. T.
Determination of Stable Isotopic Compositions of H, C, N, O, and S at the Martian Surface Using Mass Spectrometry and Stepped Combustion/Pyrolysis
- 11:30 Gerasimov M. V.*
A Possible Use of Semiconductor Gas Sensor Instrument for Investigation of UV-Decomposition of Martian Salts and Release of CL- and S-Containing Gases to the Atmosphere

Afternoon Session**Chair: I. P. Wright**

- 14:00 Klingelhöfer G.* Foh J. Held P. Jäger H. Teucher R. Kankeleit E.
Development of a Mössbauer Backscattering Spectrometer, Including X-Ray Fluorescence Spectroscopy, for the In Situ Mineralogical Analysis of the Mars Surface
- 14:30 Agresti D. G.* Morris R. V. Wills E. L. Shelfer T. D. Pimperl M. M.
Shen M.-H. Nguyen T.
A Backscatter Mössbauer Spectrometer (BaMS) for Use on Mars
- 15:00 Vistisen L.* Knudsen J. M.
Mössbauer Spectroscopy on Mars. What to Expect?
- 16:00 Knudsen J. M.* Vistisen L.
Magnetic Phases on the Martian Surface
- 16:30 Jakes P.*
Analogue of Hand-Held Lens and Optical Microscope for Martian In Situ Studies
- 17:00 Fegley B. Jr.*
COMPAS: Compositional Mineralogy Photoacoustic Spectrometer
- 17:30 Rieder R.
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Workshop Summary

J. A. Grant and A. H. Treiman

The speakers in the first session of the workshop addressed some of the continuing enigmas regarding the atmospheric composition, surface composition, and atmosphere-surface interactions on Mars; provided a description of a database of proposed payloads and instruments for SEI missions that is scheduled to be accessible in 1993; discussed potential uses of atmospheric imaging from landed stations on Mars; and advocated the collection and employment of high-spectral-resolution reflectance and emission data.

H. Wänke opened the workshop by stating his interest in constraining the role of sulphur and water in interactions between atmosphere and surface processes on Mars. He noted that the composition of SNC meteorites indirectly suggests that some episodes of martian volcanic activity would produce large volumes of SO₂, but limited CO₂. Understanding how this inferred activity relates to the origin of sulphur at the Viking Landers was cited as an important unresolved question. In addition, surface water probably plays an important role in weathering, but actual volume and occurrence of this water requires further constraint.

Other important, unresolved issues of atmospheric composition, surface composition, and atmosphere-surface interactions on Mars exist, which B. Fegley Jr. outlined in his presentation. Regarding atmospheric composition, Fegley stated that spatial and temporal variations in both tropospheric water vapor content and photochemically derived ozone require further *in situ* definition. Also, the behavior of major and trace gases in the planetary boundary layer and the abundance of other photochemically produced gases (e.g., H₂O₂, NO, and NO₂) is not completely understood. Finally, constraints on the isotopic composition of atmospheric gases would allow measurement of short- and long-term exchanges between surface and atmospheric inventories. Unresolved issues relating to surface composition include knowledge of both elemental abundances and the isotopic composition of volatiles and rocks. The mineralogical composition of the surface and the distribution of any carbonates or volatile-bearing phases also requires definition.

How these issues affect chemical weathering at the surface remains incompletely understood. For example, what are the compositions of weathered materials and how has the spatial distribution of weathered phases changed with time? Are carbonates produced? Can their occurrence be masked? How important is surface weathering due to UV photochemical reactions? How are iron phases chemically weathered? Can weathering mask the signature of various rock types? What are the details of the martian water cycle and how have they changed through time? Weathering products need to be constrained to accurately define what pristine materials are being weathered and how the atmosphere is affected by weathering. Fegley summarized by stating that subsequent presentations would describe instruments that should help to resolve many of the issues outlined.

N. G. Barlow provided context for the meeting through description of a database of proposed payloads and instruments for SEI missions. The database is in hard-copy and payload matrix format and is being compiled by the Exploration Programs Office at JSC. The name and any updates on an instrument for

either a human and robotic mission are followed by a description that includes anticipated power, data rate, and mass requirements. Next, data management strategies are described and operational constraints are cited. Required crew interactions are listed along with payload delivery options and the estimated set-up time. Subsequent sections focus on maintenance needs, technology needs, infrastructure interfaces, possible resupply needs, and the contact person for the instrument. The payload matrix is an Excel chart broken into similar sections containing more detail. Barlow stated a desire to include instruments proposed in the current meeting and instructed participants to contact her at the LPI with any updates. She concluded by indicating the information should become accessible in 1993.

Atmospheric imaging from landed stations on Mars may be a means of addressing a variety of topics according to T. Z. Martin. He began by noting that future surface imaging systems may be driven by requirements to identify mineralogy, but that these cameras could be designed to allow atmospheric monitoring also. When properly located, a landed imaging system could better define typical atmospheric opacities due to suspended dust and ice and help constrain processes of dust entrainment. Moreover, such a system could monitor conditions during fog formation/dissipation and/or directly measure the characteristics of suspended dust. Observations of the solar aureole would constrain atmospheric particle scattering, and day/night imaging (e.g., track Phobos) allows measurement of atmospheric water vapor. Possibilities for identifying the physical properties of aerosols, tracking clouds, and monitoring the formation/dissipation of the polar hood were also emphasized. Ideally, the imaging system would possess all-sky capability, obtain phase angles up to 180° , and be Sun pointing. Ability to image at a range of visible wavelengths is also important and a system triggered by wind speed or humidity would detect transient phenomena.

R. E. Arvidson explained how knowledge of the surface composition of Mars might be increased through future collection of high-spectral-resolution reflectance and emission data. He first reviewed data from the Viking Landers that revealed a complex surface whose character ranged from exposures of fresh blocks and bedrock to surfaces covered by sediment and patinas. Based on the limited spectral resolution of the Lander images, most rock surfaces appear comparable to terrestrial basalts with thin coatings of palagonite or desert varnish, although higher-spectral-resolution data is required to confirm such interpretations. Viking Orbiter data allow definition of regional surface units and suggests that the Landers are located in especially blocky areas; however, it is unclear whether these units reflect variations in surface composition, character, and/or atmospheric effects on the data. Examination of multispectral data (e.g., TIMS, AVIRIS) from terrestrial surfaces demonstrates that rock coatings ($\ll 60 \mu\text{m}$ thick) and/or weathering rinds do not mask compositional information. Moreover, the terrestrial data indicate that a system capable of collecting high-spectral-resolution data in both the visible and infrared should discern mineralogy in bedrock outcrops and exposed blocks on Mars. Arvidson also commented that this type of imaging system would complement a sampling program.

The presenters in the second session discussed the use of optical luminescence spectroscopy to probe martian surface mineralogy; expressed reservations regarding the ability of UV spectrometers to measure ozone abundance on Mars; proposed the use of a rover-deployed ground-penetrating radar to locally define near-surface stratigraphy on Mars; suggested the use of microwave spectroscopy to conduct temperature/pressure and water vapor sounding in the martian atmosphere; presented the results of UV irradiation of carbonates; and described mass spectrometric studies of the interactions between martian atmosphere gas components and ferric oxide surfaces under UV illumination.

The use of optical luminescence spectroscopy (OpL) as an active probe of martian surface mineralogy was proposed by A. H. Treiman. OpL uses light to stimulate atoms into an excited state and then records the photons given off as the atoms return to their ground state. Some elements (e.g., REE) react quickly to stimulation and produce relatively sharp absorption and emission peaks while others react at timescales longer than 10^{-2} s. Heating the slower-reacting elements causes thermoluminescence as energy stored in the crystal lattice to be released. On Mars, the inferred presence of luminescent minerals (e.g., carbonates), cold conditions, and cosmic ray exposure at the surface indicate the characteristic spectra produced by both types of elements can define composition. Effectiveness may be limited, however, if minerals incorporate significant ferric iron. OpL spectra would be taken at night when a visible–near-IR spectrometer would be idle and would ideally utilize a high-power solid-medium UV laser (under development). A UV laser would provide intense tunable light capable of targeting objects at variable range and serve multiple purposes (e.g., ranging). Alternatively, electron flux could generate optical luminescence (cathodoluminescence), but would require high power and transport of samples to the spectrometer. Finally, samples could be transported to a heating chamber (e.g., TAPS calorimeter) and made to thermoluminesce.

The ability of UV spectrometers to effectively measure ozone abundance on Mars is not certain. B. L. Lindner raised questions based on modeling results showing that scattering by dust and clouds in the atmosphere can mask true ozone concentrations. Ozone should be abundant near the surface; however, scattering by the entire atmospheric column of dust and clouds makes detection there difficult. Because the scattering properties of dust and clouds are not well known, current estimates of ozone may be low. For example, Lindner found that scattering by dust and clouds with optical depths of 0.3 and 1.0, respectively, results in a $3\times$ underestimate of ozone. Large solar zenith angles during high-latitude winters create even greater atmospheric path lengths that may account for inferred low ozone at the poles. As a benchmark of photochemical models of Mars an accurate knowledge of ozone abundances becomes important, but may not yet be possible using UV reflectance spectroscopy.

A rover-deployed ground-penetrating radar (GPR) might be used to locally define near-surface stratigraphy on Mars. J. A. Grant described GPR as a proven and relatively inexpensive instrument that uses dielectric contrasts in the subsurface to define stratigraphy and structure at a resolution of tens of centimeters horizontally, and vertically to depths of ~ 40 m. When used around terrestrial impact craters GPR identifies differing ejecta compositions, alluvium, calcic soils, faults, fractures, and bedrock. On Mars, GPR data would identify locations where ground truth would be maximized and could be extended over a broader area, thereby providing context for interpreting results of surface analyses by other instruments. A GPR could help resolve the origin of sulphates at the Viking Lander sites, identify buried ground ice or brines, and reveal stratigraphy in the polar layered terrains. Preliminary estimates of GPR dimensions are ~ 2000 cm³, ~ 2 kg, and it would use ~ 10 W.

D. O. Muhleman discussed temperature/pressure and water vapor sounding in the martian atmosphere using microwave spectroscopy. Sounding could be accomplished from either the surface or an orbiting platform and would take advantage of intense atmospheric spectral lines for H₂O and CO. Vertical resolution of temperature/pressure and water vapor profiles from surface sounding would be ~ 0.25 km up to 1 km and decrease at higher altitudes. Resultant water vapor and temperature predictions should be accurate to within 1 μ m and 1–2 K respectively. The instrument would have a mass of ~ 2 kg and require ~ 5 W. Sounding from orbit allows the entire atmosphere to be mapped every few hours at accuracies

comparable to surface sounded profiles, but with less vertical resolution. The orbiting sounder is less than ~8 kg and requires ~15 W. The wavelength of the microwave system ensures that atmospheric dust and clouds will have no effect on either mode of data collection and profiles could be generated any time.

The results of UV irradiation of carbonates were reported by L. M. Mukhin, who began by noting that photochemical processes on Mars may contribute to the chemical evolution of the surface and atmosphere and that the surface of the planet is subjected to UV irradiation. Therefore, a calcite monocrystal was UV irradiated as a first step toward understanding mineral stability under these conditions. Quantitative data collected during the experiments recorded the evolution of CO₂, possibly due to photodestruction of calcite. This effect does not appear to be related to heating of the sample; however, irradiation of additional samples is necessary to constrain how variable particle size or composition affects CO₂ release. Results imply that attempts to accurately measure carbonates on Mars may be complicated by competition between carbonate formation and photodestruction.

A. P. Koscheev presented the results of his work with L. M. Mukhin using mass spectrometry to study interactions between martian atmosphere gas components and ferric oxide surfaces under UV illumination. Mass spectrometry and thermodesorption spectroscopy methods were used to investigate the effects of UV stimulation of Fe₂O₃ powder in the presence of CO, CO₂, H₂O, and O₂. Samples were subjected to dark conditions and UV irradiation at temperatures of 200–300 K and pressures between 10⁻¹–10⁻² Torr. Under dark conditions gases were chemisorbed, which were then released upon heating and UV irradiation. Adsorbed H₂O leads to the appearance of tightly bound CO₂ whose abundance increased with increasing irradiation. Finally, experiments revealed that adsorbed CO was only released as CO₂. Koscheev stressed that their work is preliminary and that only one experimental method was used. Additional species may also be detected during future experiments.

Talks in the third session emphasized *in situ* analyses of volatile components in martian regolith by thermal methods: heating the regolith and analyzing the gases that are released. Many different thermal analyses schemes are available, and there was much discussion about which are most appropriate for lander-based measurements on Mars. Ideally, these methods will provide analyses of the volatile content of the martian regolith, and semiquantitative data on the mineral phases in which the volatiles reside. Some methods would also provide isotope analyses for C, O, and S, which would be important for understanding atmosphere-surface chemical interactions. However, complex materials may yield poorly interpretable patterns of thermal effects and gas releases. In addition, samples with different grain size distributions may have distinctly different patterns of thermal effects and gas releases. The gas-analytical systems in these instruments could be shared among other experiments, including atmosphere analysis and soil reactivity. The heating systems could be shared with other experiments, such as thermoluminescence spectroscopy.

The principles of thermal analysis and a description of a differential thermal analysis-gas chromatography (DTA-GC) instrument were the subject of R. L. Mancinelli's presentation. In DTA, a sample and a standard are continuously heated, and the temperature difference between them records absorption or release of heat by the sample. The proposed instrument could heat samples to 1200°C. Released gases would be analyzed by GC, in which the gases are separated by how strongly they are adsorbed onto selected substrates. GC can provide good quantitative analyses of gas species, but is insensitive to isotopic abun-

dances. This DTA/GC analyzer is at a high level of technical development, as the DTA is listed for both MESUR and Mars'96, and the GC is similar to that developed for CRAF.

K. Mauersberger described a multisample thermal and gas analysis system using pyrolysis and mass spectrometry (MS). This instrument would heat regolith samples in temperature steps and analyze the evolved gas at each step for bulk and isotopic composition. Regolith samples would be fed into sapphire cells on a turntable (six to eight cells), which would then be rotated to bring a given sample to a heating chamber. Stepped heating to 1000°C would be accomplished by conventional means. The evolved gases would be fed into a quadrupole field mass spectrometer (QMS) and analyzed. An active vacuum pump would be important if more than a few samples were to be analyzed. Instruments in this system have a long space-flight heritage including the Viking CGMS experiment. The proposed system would permit analyses of elemental and isotopic abundances of volatiles in many samples, but could not evaluate heat effects during heating, nor temperature profiles of gas precise releases. With an ion-getter vacuum pump, and configured for a analysis of a single sample, this instrument would weigh 4 kg; with a turbomolecular vacuum pump (under development), and configured for multiple samples, this system would weigh 5.5 kg.

The TAPS instrument (Thermal Analyzer for Planetary Soils) is currently under development and was described by D. W. Ming. TAPS uses differential scanning calorimetry (DSC) to measure heat effects, and a solid-state sensor for analysis of evolved water. In DSC, a sample and standard are heated independently so that they stay at the same temperature; heat effects are thus measured directly. In the TAPS instrument, a regolith sample would be heated continuously to 1000°C. Effluent gas from DSC would pass over a solid-state water sensor (capacitive-polymer type); other solid-state sensors could be accommodated. Instruments similar to TAPS have been designed for space missions, but never flown. In the present design, TAPS would weigh 1.5 kg, and draw 5 W maximum. TAPS would provide quantitative estimates of abundances of volatile-bearing minerals in the regolith, in addition to mineral identification and volatile inventory. TAPS includes its own sample collection system, but must be emplaced onto the regolith to perform analyses.

At this point, Dr. S. Linkin of the Babukin Center, Russia, gave a short description of the Mars '94-'96 spacecraft and their status with respect to technical and political issues.

Next, Ian Wright presented a paper describing a conceptual scheme for high-precision isotope measurements of light elements (C, H, O, N, and S) from volatiles and silicates. The isotope measurement would be of a quality comparable to that obtained routinely on Earth, notably in obtaining abundance ratios for the three oxygen isotopes. The proposed scheme would start with stepped combustion and/or pyrolysis of a regolith sample; oxygen for combustion could be provided by a solid reagent. Evolved gases would then be chemically separated so that a single species would be measured at a time; separation could be effected by gas chromatography, cryogenic cooling, or chemical reactions. Separated gases would flow into a high-precision neutral gas mass spectrometer, which would have been calibrated against a reference gas. Stepped fluoridation reactions would permit measurement of oxygen isotopes in silicates and sulfur isotopes on sulfides. The proposed instrumentation derives from that used routinely on Earth; similar mass spectrometry systems have been flown in space and the pyrolysis/combustion system could follow the previous designs. The gas separation and chemical reactivity steps are at the conceptual development stages.

The final talk of the session was by M. V. Gerasimov on the photochemical devolatilization of chlorides and sulfates and the use of solid-state sensors to analyze gas compositions. First, data was presented showing that chloride and sulfate minerals may decompose under the direct action of short-wave ultraviolet (UV) light, such as hits the surface of Mars. The compositions of evolved gases in the Mars atmosphere can be measured using an array of semiconductor (metal-oxide) resistivity films. The electrical resistance of each film sensor is strongly affected by gases adsorbed from the ambient atmosphere; different films are sensitive to different gases. Concentrations of O₂, CO, H₂O, and H₂ are readily determined; concentrations of S, Cl, and O₃ may also be measurable. The observation of photochemical volatilization was new to most participants, and elicited much discussion. The gas sensor array has been demonstrated in the lab, but has not been developed or flown on spacecraft. The array would require only 50 mW power, could be used in chemical analysis instruments, and requires a resistance meter with a large dynamic range (10³-10⁷ ohms).

The first half of the last session dealt with investigations of magnetic properties of the martian surface. Three talks described Mössbauer spectrometers and spectroscopy as probes of the magnetic and iron-bearing mineralogy of the surface. There was general consensus a Mössbauer spectrometer would be an important instrument for *in situ* analyses of Mars' surface. The final portion of the workshop was reserved for instruments or concepts that were outside the other focused sessions. The talks were on optical "hand-lens-scale" microscopy, photoacoustic optical spectrometry, and alpha-particle backscatter instrumentation.

G. Klingelhöfer described the physics of Mössbauer spectroscopy and a spectrometer design under development for the Mars'96, Marsnet, and MESUR missions. Mössbauer spectroscopy operates by detecting energies at which nuclear gamma rays are absorbed by an iron isotope, and relating the shifts to electric and magnetic field strengths at an iron atom's nucleus. Mössbauer spectroscopy permits direct identification of Fe-bearing minerals, if present in sufficient quantity and in relatively simple mixtures, and semiquantitative determination of mineral proportions. Most Mössbauer spectroscopy on Earth is done in transmission mode, but backscatter mode permits natural sample geometries.

The workshop was shown a working prototype backscatter Mössbauer spectrometer, representing a high level of technical development. The instrument and its electronic controls are about the size of a soda can (700 cm³), weigh less than 400 g, and consume less than 1.5 W during operation. The instrument may be modified to permit analyses of chemical compositions by the X-ray fluorescence (XRF) technique, pending development of solid-state ambient temperature X-ray detectors with improved energy resolutions.

The following talk, by D. G. Agresti, described his group's development of a backscatter Mössbauer spectrometer suitable for MESUR, lunar (Artemis), and other planetary studies. This instrument and that of Klingelhöfer and others are quite similar, representing a convergence of design solutions. As with the above design, backscatter Mössbauer spectrometers may also provide some information on compositional changes with depth into the sample. The instrument, presented as a working prototype, is projected to a final mass of less than 500 g, volume of less than 300 cm³, and power consumption less than 2 W.

L. Vistisen discussed interpretations of backscatter Mössbauer spectroscopy of model analogues to martian surface materials. It was shown that backscatter Mössbauer spectra such as could be acquired on

Mars would permit mineral identifications to almost the same accuracy as is possible on Earth with transmission Mössbauer spectra. A spacecraft-borne backscatter Mössbauer spectrometer could successfully resolve and identify at least three Fe-bearing minerals (olivine, titanomagnetite, and ilmenite) in a natural basalt matrix, and could identify macrophase hematite and other ferric oxides in a regolith.

The final talk on magnetic experiments was by J. M. Knudsen, who talked about the identification of magnetic minerals in the martian soil by magnetic separation. It was proposed that a martian lander should carry a series of five to eight small permanent magnets, weaker than those on the Viking landers, to permit grain separations according to their saturation magnetizations. With an additional heat source, grains adhering to the magnets could be heated so as to measure their Curie temperatures. This scheme could yield mineral separates, which could then be analyzed by other methods. The five-magnet experiment would be extremely cheap and light (<100 g) and would consume no power. It would require, however, both a manipulator arm and a visible–near-IR imaging system. The heating/separation scheme would require both power and additional mass, which were not detailed.

The final half-session of the workshop was devoted to singular presentations. First, P. Jakes reminded the attendees about the value of low-magnification ($\sim 10\times$) visible imagery for rock and mineral identification, and proposed a “hand-lens” for planetary surface investigations. Terrestrial studies of rocks, sediment or regolith use $\sim 10\times$ magnification imagery from the beginning because (1) many mineral grains and structures in geological materials are resolved at that scale and (2) the human eye and brain are superb at pattern recognition. Jakes presented a video of a prototype instrument consisting of a fixed-focus optical system, self-contained illumination, and a CCD camera. The instrument is designed to be placed on the object of interest, and provides images that are readily interpretable as to grain sizes, shapes, and colors. The whole instrument would probably weigh less than 100 g and have a volume of less than 100 cm³.

B. Fegley Jr. described work performed by W. H. Smith on photoacoustic spectroscopy as a method for obtaining visible–near-IR absorption spectra *in situ*. Photoacoustic spectroscopy operates by illuminating the unknown with an amplitude-modulated beam of monochromatic light, and scanning the wavelength of the light. When incident light is absorbed, the unknown sample will expand and contract in phase with the amplitude modulation, yielding sound that is detected by the sensor. Thus, photoacoustic spectroscopy can yield a direct visible-IR absorption spectrum on an unprepared, opaque sample. Instrumentation is under development that is aiming for volume < 125 cm³, mass < 110 g, and power consumption of <1.5 W. Spectra will be measured over at least 0.7–2.5- μm wavelength, with extensions to shorter and longer (thermal IR wavelengths).

Finally, R. Rieder discussed alpha-particle backscatter spectrometry (also called Rutherford Backscatter) and PIXE (proton-induced X-ray emission) spectrometry for probes of planetary surfaces. Instruments of these types have been used since the Surveyor lunar missions; more recently they have flown on Phobos and are scheduled to fly with the Mars’94 and Mars’96 missions. Both methods together allow bulk chemical analyses of rock or regolith surfaces; alpha backscatter is sensitive to light elements (C, O), while PIXE is more sensitive to heavier elements (Na to Fe and heavier). In operation, a source of alpha particles is brought near the sample, and re-emission from the sample is measured as a function of particle/photon energy and emission angle. For PIXE, protons are produced within the sample as elemental nuclei react with the incident alpha particles.

List of Workshop Participants

David G. Agresti

*Department of Physics
University of Alabama
Birmingham AL 35294-1170*

Raymond E. Arvidson

*Department of Earth and Planetary Sciences
Washington University
St. Louis MO 63021*

Nadine G. Barlow

*Mail Code XI
SYSCOM
NASA Johnson Space Center
Houston TX 77058*

Vitalii Bondarev

*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

William Boynton

*Department of Space Sciences
University of Arizona
Tucson AZ 85721*

Johannes Brückner

*Max-Planck-Institut für Chemie
Saarstrasse 23
6500 Mainz
GERMANY*

Guennadi Dolnikov

*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

Gerlind Dreibus

*Max-Planck-Institut für Chemie
Saarstrasse 23
6500 Mainz
GERMANY*

Evgenii Evlanov

*Space Research Institut
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

Utz Fabian

*Max-Planck-Institut für Chemie
Saarstrasse 23
6500 Mainz
GERMANY*

Bruce Fegley

*Department of Earth and Planetary Sciences
Washington University
St. Louis MO 63130-4899*

Michael V. Gerasimov

*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

John A. Grant

*Department of Geological Sciences
Box 1846
Brown University
Providence RI 02912*

Petr Jakes

*Faculty of Science
Department of Economic Geology
Albertov 6
Praha 2
12843 Czechoslovakia*

E. Kankleit

*Technische Hochschule Darmstadt
Institut für Kernphysik
Schlossgartenstrasse 9
6100 Darmstadt
GERMANY*

G. Klingelhöfer

*Technische Hochschule Darmstadt
Institut für Kernphysik
Schlossgartenstrasse 9
6100 Darmstadt
GERMANY*

Jens Martin Knudsen

*H. C. Ørsted Institute
Universitetsparken 5
2100 Copenhagen
DENMARK*

Alexander P. Koscheev
*Karpov Institute of Physical Chemistry
ul. Obukha 10
103064 Moscow E-64
RUSSIA*

Vladimir Khromov
*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

Bernhard Lee Lindner
*AER
840 Memorial Drive
Cambridge MA 02139*

Slava Linkin
*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

Rocco L. Mancinelli
*Mail Stop 239-12
NASA Ames Research Center
Moffett Field CA 94035-1000*

Terry Z. Martin
*Mail Stop 169-237
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109*

Konrad Mauersberger
*School of Physics and Astronomy
University of Minnesota
116 Church Street SE
Minneapolis MN 55455*

Doug Ming
*Mail Code SN4
NASA Johnson Space Center
Houston TX 77058*

Duane O. Muhleman
*California Institute of Technology
Pasadena CA 91125*

Lev M. Mukhin
*Embassy of the Russian Federation
1125 16th Street NW
Washington DC*

Nikolai Porshnev
*Space Research Institute
Russian Academy of Sciences
ul. Porfsoyuznaya 84/32
Moscow 117810
RUSSIA*

Rudolf Reider
*Max-Planck-Institut für Chemie
Saarstrasse 23
6500 Mainz
GERMANY*

H. Rosenbauer
*Max-Planck-Institut für Aeronomie
Max-Planck-Strasse 2
Postfach 20
3411 Katlenburg-Lindau/Harz
GERMANY*

Allan H. Treiman
*Mail Code SN4
NASA Johnson Space Center
Houston TX 77058*

Claude d'Uston
*CESR
9 Avenue du Colonel Roche
BP 4346
31029 Toulouse cedex
FRANCE*

V. Vanzani
*Dipartimento di Fisica
Universita di Padova
Via Marzolo 8
35131 Padova
ITALY*

Lise Vistisen
*Niels Bohr Institute
Blegdamsvej 17
2100 Copenhagen
DENMARK*

Heinrich Wänke
*Max-Planck-Institut für Chemie
Saarstrasse 23
6500 Mainz
GERMANY*

Ian Wright
*Department of Earth Sciences
Open University
Walton Hall
Milton Keynes MK7 6AA
ENGLAND*